

LA-UR-01-3701

*Approved for public release;
distribution is unlimited.*

Title:

USE OF SIMULATION TO EXAMINE OPERATIONAL SCENARIOS
IN A LATHE GLOVEBOX FOR THE PROCESSING OF NUCLEAR
MATERIALS

Author(s):

Melissa McQueen, Pradeepkumar Ashok, Daniel J. Cox
Robotics Research Group
The University of Texas at Austin

Pete Pittman, ESA-EPE
Cameron J. Turner, NMT-15
Robert Hollen, ESA-EPE
Los Alamos National Laboratory

Submitted to:

Proceedings of the American Glovebox Society 2001 Conference
and Exposition
San Diego, California
July 16-18, 2001

Los Alamos
National Laboratory

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

FORM 836 (8/00)

Use of Simulation to Examine Operational Scenarios in a Lathe Glovebox for Processing of Nuclear Materials

Melissa McQueen, Pradeepkumar Ashok, Daniel Cox
Robotics Research Group, the University of Texas at Austin, PRC/MERB 1.206
Mail Code R9925, Austin, TX 78729-1100 USA
e-mail: dc Cox@mail.utexas.edu
Tel: (512) 471-5182

Cameron J. Turner, Pete Pittman, Robert Hollen
Los Alamos National Laboratory, P.O. Box 1663, MS J580, Los Alamos, NM 87545
Email: cturner@lanl.gov
Tel: (505) 665-4646

ABSTRACT

In the process of dispositioning nuclear materials into storage, the use of a robot eliminates the safety risks to humans and increases productivity. The current process of processing typically uses humans to handle the hazardous material using gloves through glove-ports. This process is not only dangerous, but also costly, because humans can only be subjected to limited exposure to nuclear materials due to the actual Occupational Radiation Exposure (ORE) and thus have a fixed amount of dedicated workload per unit time. Use of robotics reduces ORE to humans and increases productivity. The Robotics Research Group at the University of Texas at Austin has created a simulation model of a conceptual application that uses a robot inside the glovebox to handle hazardous materials for lathe machining process operations in cooperation with Los Alamos National Laboratories (LANL). The actions of the robot include preparing the parts for entry into the box, weighing the parts, positioning the parts into the headstock chuck of the lathe, handling the subsequent processed parts, changing and replacing the lathe tools and chuck assemblies are necessary to process the material. The full three-dimensional geometric model of the simulation demonstrates the normal expected operation from beginning to end and verifies the path plans for the robot. The emphasis of this paper is to report additional findings from the simulation model, which is currently being expanded to include failure mode analysis, error recovery, and other what-if scenarios involved in unexpected, or unplanned, operation of the robot and lathe process inside of the glovebox.

INTRODUCTION

The processing of nuclear materials such as plutonium, into a form used for the storage, disposal, and inspection for usability is done inside of the Advanced Recovery and Integration Extraction System (ARIES) process line developed by LANL. The gloveboxes that make up the ARIES system are the Bisector, Hydride/Dehydride, Canning, Electrodecontamination and the Lathe Glove Box (LGB). The processes inside of these containment units are automated in order to reduce ORE to the operator by reducing contact between the operator and the nuclear material. Simulation of the lathe machining process inside of the LGB gives The Robotics Research Group (RRG) at the University of Texas (UT) the ability to examine operational scenarios that could lead to potential failures as well as the safety of using an automated lathe process inside of a glovebox.

COMPUTER MODEL

Movement of tools and material inside of the LGB is done by a 4 degree of freedom automated gantry robot system. First the plutonium part enters the containment unit through an airlock. The robot arm places the pot chuck onto the tailstock and the headstock with a specific end effector. Once the cutting tool is positioned inside the tool post, then the part is placed onto the lathe and the cut is performed. After the cut has been completed the denesting process begins. Finally each half of the part is weighed and transferred to the next glovebox. The geometry of the model and the simulation was created in a Cimatrix¹ and an external program runs the simulation (Figure 1). The robotics group uses this visualization to identify failure scenarios specific to the path of the robot arm. These are the paths that the robot takes to complete each task during the lathe machining process. The simulation model was completed from mechanical detail drawings specifications supplied by LANL. Cimatrix models accept simple shapes only, thus the general geometry was modeled.² For example the headstock has numerous cooling indentations, but was modeled as a solid cylinder.²

In addition to the observed potential for failure due to the simulation constraints, there are also general failures that can occur when the robot is not completing a specific operation. This paper is based on the failure mode analysis done to predict and rank failures, causes, prevention, and recovery in order to obtain a risk priority measurement for each failure. These assessments are made through Failure Mode and Effect Analysis (FMEA) and also suggest failure recovery strategies.

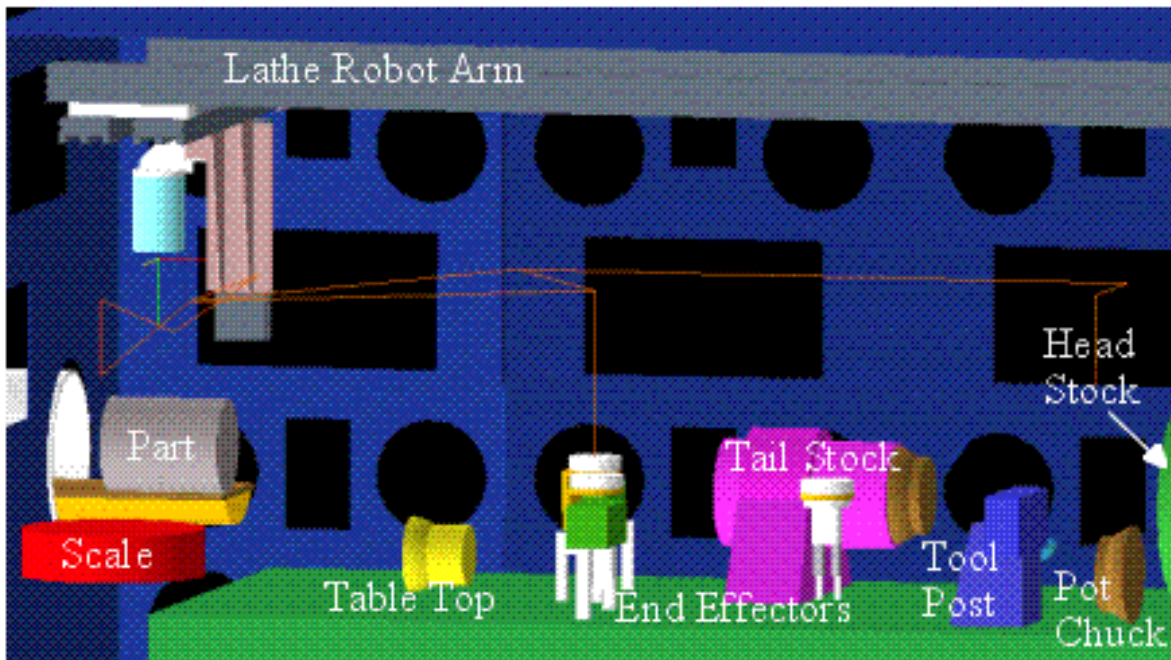


Figure 1. Inside the ARIES Lathe Glovebox: Part Placement Path. Tools and materials include, robot arm, part, scale, end effectors, tool post, pot chuck as well as the tailstock and the headstock of the lathe.²

FMEA APPROACH

Simulation was used because of the many advantages of not having to wait until after the system has been manufactured. It is less costly to run failure modes on a simulation because there is no chance of damaging expensive equipment. It is less time consuming because there is no need to wait for setup, calibration, parts, or materials before viewing the process. Safety is also a consideration because by running a simulation, there is no danger of damaging any equipment or harming an operator due to an accident caused by a failure. The simulation was done taking into consideration four key operations:

1. Pot chuck placement: Involves the robot picking up the pot chuck from its station and placing it on the headstock.
2. Tool placement: Involves the robot picking up of tool and placing it on the tool post.
3. Part placement: Placement of the part between the headstock and the tailstock by the robot.
4. Part weighing process: Weighing of the part after the denesting process.

There are a multitude of paths that can be used to implement the above key operations as well as several different ways to analyze them:

1. Make an analytical model: The magnitude and complexity involved makes this approach time consuming and inaccurate.
2. Analyze every possible path: This would take an extensive amount of computer power and was also considered time consuming and expensive.
3. Use simulation: The Cimatrix simulation was used to come up with reasonable path variations for each of the key operations and these paths were used to logically do the failure mode analysis. Not only was this methodology less time consuming and less expensive, but also being more intuitive added to a better comprehension of the process limitations and hazards.

The robotics group investigated the pot chuck placement, tool placement, part placement and the part weighing processes. Some of the potential failures visible from the simulation include collisions within the interior of the glovebox. The probability (P) that a specific failure will occur on a scale of 1 to 10 means that for a value of 1, it is very unlikely that the failure would occur, and a value of 10 means that it is certain that the failure would be happen. These failure events can be ranked in severity (S) from 1 to 10, with 10 being a failure directly related to safety and 1 being no affect to the worker at all. The likelihood that a failure will occur is dependent on the cause of the failure. Whether or not the failure is likely to be detected (D) by the operator is also ranked from 1 to 10, with 10 being extremely unlikely that the error is detected, and 1 being that it is an error that would be detection immediately. The detection values are based on the mode of indication. The operator detects these incidents of failure visually. A force sensor signal, or a barrier sensor that has limits set by the program controlling the movement of the robot also indicates failures. Probability, cause and indication measures described above are multiplied to arrive at the Risk Priority Measure. A high value suggests that a particular failure is critical and hence the process needs to be more controlled.

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
1	Arm not properly homed	All	1.Position sensor is misaligned	1. Collision / Impending collision 2. Loss in accuracy	5	9	7	315	1. Calibrate the sensors regularly 2. Have backup sensors at the homing station 3. Run diagnostic test every time the system is booted	Shut down the system and replace / recalibrate the sensors

Figure 2. Analysis of the failure mode “Arm not properly homed.”

Figure 2 showcases the worst-case scenario failure mode associated with the operation of the robotic arm in the glove box. The high risk priority measure occurs when the arm is not properly homed due to a misaligned motion sensor. This type of failure would be indicated visually due to an impending collision or loss in accuracy and has a low probability of occurring. The least risk priority measure is due to a failure in picking up the pot chuck due to the wrong end effector chosen for the pot chuck. This type of failure is indicated only visually by the operator and is a slight inconvenience and an unlikely occurrence. This high risk priority measurement failure is not as intuitive because the state of the robot arm not being homed is not much of a risk by itself but it is the consequences that come with it, such as collisions with other tools or possibly even a collision with the glovebox itself.

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
1	Failure of robot arm to properly pick up part	1. Weighing the part 2. Denesting of Part 3. Part placement	1. End effector not properly aligned with part	Visual	4	10	8	320	1. Make sure the homing process is done correctly.	Shut down the system. Clean the system; replace the part to its designated spot.

Figure 3. Analysis of the failure mode “Failure of robot arm to properly pick up part.”

The second major risk hazard occurs if the robot arm fails to properly pick up the plutonium part with the end effector. (Appendix 1) This creates a possibility for a radiation exposure hazard. If the part is dropped then the system will have to be shut down and cleaned out. This failure could cause problems if the part is broken because of the risk of sharp edges and exposure to the operator. The next major range of risk priority measurements comes when the robot arm fails or collides with something inside of the glovebox. Since there is no way for the robot to sense excess materials inside, care must be taken to avoid the possibility of a collision by making sure that excess tools and material are always removed if not being used.

The safety risks involved with the handling of nuclear material in a containment unit such as a glovebox are minimal as long as the glovebox is securely sealed. Once there is a leak due to an improper seal or a torn glove there is danger of exposure to the worker. One way to prevent this is to have the system inside the glovebox at negative pressure. The negative pressure keeps potentially harmful materials from exiting the glove box and exposing the user. A failure indicator such as a glove box pressure indicator can signal when the pressure inside the glove box changes to a higher level. This indication of an out of range pressure level inside of the glovebox is also considered a high risk measurement although it is very easy to detect the severity of such a failure is very high. (Appendix 1)

CONCLUSION

The best way to keep the glovebox environment safe as a containment unit is to continuously monitor the system so that the operator will be able to continuously determine the state of the system. Hazards are minimized when the operator is trained sufficiently in being able to recognize these signals and act accordingly to reduce the chance of potential failures from becoming more severe. A list of possible failures and recovery methods should be outlined and made available to everyone who operates in this environment. Simulations like the one described here in this document can be used to help train operators on what to look for in the way of possible failures that can occur while the system is running. This type of visualization makes it easy for an operator to get the big picture on how a single failure can affect several different stages of the process without having to physically be faced with a failure scenario for the first time.

ACKNOWLEDGEMENTS

This work was conducted under contract #1557-00-23 with the Los Alamos National Laboratory (LANL). The authors gratefully acknowledge both their funding and support. Furthermore, this work would not have been possible without the assistance of Dr. Pete Pittman, Dr. Chris James and Dr. Robert Hollen of LANL. Appreciation of the assistance of Cameron Turner in assisting with the collecting and reviewing the information in this paper is also gratefully acknowledged.

REFERENCES

- ¹ Product Literature, Cimatrix Inc. 6976 South High Tech Drive, Salt Lake City, UT 84047-3757. (801) 256-6500, 2000. <http://www.cimatrix.com>.
- ² Foster, C., Ashok, P., Cox, D., Tesar, D., Pittman, P., and Turner, C. "*Computer Model and Simulation of a Glove Box Process*," LA-UR-01-314, American Nuclear Society 9th Topical Meeting on Robotics and Remote systems, Seattle, Washington, March 2001.

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
1	Arm not properly homed	All	1.Position sensor is misaligned	1. Collision / Impending collision 2. Loss in accuracy	5	9	7	315	1. Calibrate the sensors regularly 2. Have backup sensors at the homing station 3. Run diagnostic test every time the system is booted	Shut down the system and replace / recalibrate the sensors
			2.Program / Software error	1. Collision / Impending collision 2. Loss in accuracy	2	9	7	126	1. Make software robust through more testing 2. Have a diagnostic test run every time the system is booted	Shut down the systems and troubleshoot program
2	Robot Arm Collision with Headstock tailstock, toolpost, scale, shuttle	All	1. Arm not properly homed	Visual	4	5	8	160	1. Make sure the homing process is done correctly 2. Restricted range of motion programmed into controller	Shut down the system, Replace the damaged parts and follow recovery procedure for "Arm not properly homed"
			2. Position sensor misalignment	Visual	5	5	8	200	1. Calibrate the sensors regularly	
			3. force torque transducer sensor calibration error	Visual	6	5	8	240	1. Calibrate the sensors regularly	
3	Failure of robot arm to properly pick up									
	a. end effector	All except "Cutting the part"	1. Arm not properly aligned with end effector	1. Visual 2.Signal	4	5	8	160	1. Make sure the homing process is done correctly.	Shut down the system. Rehoming the system, replace the end effector, if damaged and place it at the end effector station.
			2. Damaged end effector	1. Visual 2.Signal	6	5	2	60	2. Calibrate the sensors regularly	
			3. Failure of attachment	1. Visual 2.Signal	6	5	2	60	1. Plan path carefully so as to avoid close contact	
			4.End effector not at its station	1. Visual 2.Signal	6	5	2	60	1. Design better attachment.	
									1. Use sensors to confirm that the end effector is at the station.	
	b. pot chuck	1. Pot chuck placement	1. End effector not properly aligned with pot chuck	Visual	4	5	8	160	1. Make sure the homing process is done correctly.	Shut down the system. Rehoming the system, replace the pot chuck at its home position.
			2. Damaged end effector	1. Visual 2.Signal	6	5	2	60	2. Calibrate the sensors regularly.	
			3. End effector force torque transducer sensor wrongly calibrated	Signal	7	5	4	140	1. Plan path carefully so as to avoid close contact.	Shut down the system, replace the end effector, rehome the system
			4. Wrong end effector chosen for pot chuck	Visual	2	5	5	50	1. Calibrate the sensors regularly.	Shut down the system and recalibrate the sensors.
									1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program.

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
	c. tool	1. Tool Placement	See 3b							
	d. part	1. Weighing the part 2. Denesting of part 3. part placement	1. End effector not properly aligned with part	Visual	4	10	8	320	1. Make sure the homing process is done correctly. 2. Calibrate the sensors regularly	Shut down the system. Clean the system of the spillage, replace the part to its designated spot.
			2. Damaged end effector	1. Visual 2. Signal	6	10	2	120	1. Plan path carefully so as to avoid close contact.	Shut down the system. Replace the end effector, rehome the system and clean the system if necessary.
			3. End effector force torque transducer sensor wrongly calibrated	Signal	7	10	4	280	1. Calibrate the sensors regularly.	Shut down the system. Recalibrate the sensors, clean the system if necessary.
			4. Wrong end effector chosen for a particular part	Visual	2	10	5	100	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems. Troubleshoot program and clean the system if necessary.
4	Failure placing the following objects in correct position									
	a. end effector	All	1. Arm not properly aligned with end effector station	Visual	4	4	8	128	1. Make sure the homing process is done correctly. 2. Calibrate the sensors regularly.	Shut down the system, Reposition the end effector and rehome
			2. Damaged end effector	Visual	5	4	8	160	1. Plan path carefully so as to avoid close contact.	Shut down the system, Replace the end effector and rehome
			3. Software failure	Visual	2	4	7	56	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program
	b. pot chuck	Pot chuck placement	1. End effector not properly aligned with pot chuck	Visual	4	4	8	128	1. Make sure the homing process is done correctly. 2. Calibrate the sensors regularly.	Shut down the system, Reposition the end effector and rehome
			2. Damaged end effector	1. Visual 2. Signal	6	4	2	48	1. Plan path carefully so as to avoid close contact.	Shut down the system, replace the end effector, rehome the system
			3. Software failure	Visual	2	4	7	56	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program
			4. Chuck vacuum sensor not working	Sensor signal output	2	4	2	16	1. Calibrate sensors on a regular basis.	Shut down system, check suction air pressure or calibrate sensor.
	c. tool	Tool Placement	See 4b							
	d. part	Weighing the part	1. End effector not properly aligned with part	Visual	4	5	8	160	1. Make sure the homing process is done correctly. 2. Calibrate the sensors regularly.	Shut down the system. Clean the system, replace the part to its designated spot.
			2. Damaged end effector	Sensor signal output	6	10	2	120	1. Plan path carefully so as to avoid close contact.	Shut down the system. Replace the end effector, rehome the system, clean the system if necessary.

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
			3. End effector force torque transducer sensor not calibrated properly	Sensor signal output	7	10	4	280	1. Calibrate the sensors regularly.	Shut down the system. Recalibrate the sensors, clean the system if necessary.
			4. Wrong type of end effector	Visual	2	10	5	100	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program, clean inside of glovebox if necessary
5	Dropping of object									
	a. end effector	All	1. Collision	1. Visual 2.Signal	5	7	2	70	1. Plan path carefully so as to avoid close contact.	Shut down the system, Replace the end effector and rehome
			2.Program / Software error	1. Visual 2.Signal	2	7	8	112	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program
			3. Loose end effector attachment	1. Visual	4	7	5	140	1. Make sure that the attachment is locked.	Shut down the systems, check end effector and for damage, replace or tighten end effector
	b. pot chuck	Pot chuck placement	1. Collision	1. Visual 2.Signal	5	4	2	40	1. Plan path carefully so as to avoid close contact.	Shut down the system, Replace the pot chuck if damaged and rehome
			2.Program / Software error	1. Visual 2.Signal	2	4	8	64	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program
			3. Loose attachment	1. Visual	4	4	3	48	1. Make sure that the attachment is locked.	Shut down the systems. Check end effector for damage, replace or tighten end effector.
	c. tool	Tool Placement	1. Collision	1. Visual 2.Signal	5	4	2	40	1. Plan path carefully so as to avoid close contact .	Shut down the system. Replace the tool and rehome.
			2.Program / Software error	1. Visual 2.Signal	2	4	8	64	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems. Troubleshoot program.
			3. Loose attachment	1. Visual	4	4	3	48	1. Make sure that the attachment is locked.	Shut down the systems. Check end effector for damage, replace or tighten end effector
	d. part	Weighing the part	1. Collision	1. Visual 2.Signal	5	10	2	100	1. Plan path carefully so as to avoid close contact .	Shut down the system. Replace the pot chuck if damaged and rehome.
			2.Program / Software error	1. Visual 2.Signal	2	10	8	160	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program
			3. Loose attachment	1. Visual	4	10	3	120	1. Make sure that the attachment is locked.	Shut down the systems. Check end effector for damage, replace or tighten end effector. Check LVDT for alignment.
6	System failure									
	a. robot arm	All	1. Hardware failure	1. Impending collision 2. Robot stops moving 3. Robot moves erratically	4 4 4	10 10 10	4 1 1	160 40 40	1. Use robust motors and control system.	Shut down system . Replace defective item
			2.Software failure	1. Impending collision 2. Robot stops moving	2 2	10 10	2 1	40 20	1. Be certain that the software has no bugs or is correctly written.	Shut down the systems and troubleshoot program

Sr No.	Failure Mode	Processes Affected (When /Where)	Cause	Indicators	P	S	D	Risk Priority Measure	Recommended action for prevention	Recommended action for recovery
	b. lathe	Cutting the part	1.Hardware/motor failure	Visual	3	8	1	24	1. Use robust motors and control system.	Shut down System . Replace defective item
			2.Tool broken	Visual	5	8	3	120	1. Replace tool periodically.	Replace tool
			3.Tool post position error	1. Impending collision	2	8	5	80	1. Calibrate sensors periodically.	Shut down system . Reposition toolpost and cutting tool.
					2	8	1	16		
			4.Tail stock position error	1. Incorrect cut	2	8	1	16	1. Calibrate sensors periodically.	Shut down system . Check tool position.
					2	8	3	48	1. Verify toolpost and cutting tool position before cut.	Shut down system . Check pot chuck alignment
			5. Temperature out of range	3. Thermocouple readout value	4	8	5	160	1. Test thermocouples regularly.	Stop Lathe and let system cool down.
	c. axis failure	All	1. Motor failure	1. Robot stops moving	2	8	1	16	1. Run diagnosti c test on motor.	Shut down system. Replace motor.
				2. Warning signal						Shut down system, check belts for alignment and replace if necessary.
			2. Belt failure	1. Robot stops moving	2	8	5	80		
	d. Pressure out of range	All	1. Pressure sensor failure	1. Gloves appear more limp than usual 2. Pressure gage readout 3. Pressure sensor signal	4	10	4	160	1. Constantly monitor pressure inside glovebox. 2. Install warning signal to go off when undesired pressure range is imminent	Shut down system, perform a pressure check.

Score	P = Occurance	S = Severity	D = Detection
1	Very unlikely	No effect to customer	Found immediately
2	Unlikely	Minor defect	Easily found
3			
4	Low probability	Slight inconvenience	Highly likely
5			
6	Likely	Moderate inconvenience	Likely
7			
8	Highly likely	Will not work	Unlikely
9			
10	Certain	Safety related failure	Extremely unlikely

List of Processes	Description
1. Pot chuck place	The robot picks up the end effector, and then picks up the potchuck. It then places the potchuck on to the headstock. The end effector is released at the end effector station at the end of this cycle.
2. Tool placement	The robot picks up the tool gripper, and then picks up the cutting tool. The cutting tool is placed on the tool post and the robot returns the tool gripper at the end effector station
3. part placement	The robots pickup the the part end effector, places the part onto the lathe, and then releases the part end effector at the end effector station
4. Cutting the part	The lathes is turned on and the tool post moved to cut the part
5. Denesting of the	The Robot places the denesting tool on the tailstock and returns, after which the denesting is done
6. Weighing of the	The robot using the part end effector transfers each half of the part to the weighing station and then back to the shuttle.